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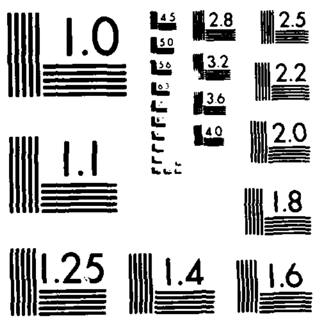

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Control canonical forms play an important role in the anlysis of finite-dimensional problems in control theory. The goal of this research was to extend these results and develop control canonical forms for infinite-dimensional systems. These results were derived for a broad class of problems, including some with unbounded input (as occurs with boundary control problems). This analysis led to approximate feedback control methods (i.e., using finite-dimensional controls) by truncating the resulting series which solves the eigenvalue specification problem. Reults were published in a series of five papers, including "Canonical forms for a class of distributed parameter control systems", "Spectral assignability for distriubted parameter systems with unbounded scalar control", and "Spectral determination for a cantilevel beam."

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Final Report for AFOSR Grant 86-0079

Richard Rebarber, Department of Mathematics and Statistics,
University of Nebraska - Lincoln

I have been studying the control theory of linear distributed parameter systems. Most of the work I have done during the grant period 4/1/86 to 3/31/88 is contained in five papers which I have included with this report. I will refer to these papers by the following numbers: 1) "Canonical Forms for a Class of Distributed Parameter Control Systems", 2) "Spectral Assignability for Distributed Parameter Systems with Unbounded Scalar Control", 3) "A Class of Meromorphic Functions Used for Spectral Determination", 4) "Spectral Determination for a Cantilever Beam", and 5) "Stabilization for a Class of Unbounded Systems" (with Gareth Knowles). Papers 1 and 2 were accepted by the SIAM Journal of Control and Optimization in January of 1988, and paper 4 was accepted (subject to revision) by the IEEE Transactions on Automatic Control in February of 1988. Preliminary versions of papers 1 and 3 were completed befcre the grant started, but several new results were added to 1, and 3 was almost completely revised during the grant period. Paper 5 is not yet completely written, although the research has been completed - I have included the first and fourth of the four sections of the paper. I will briefly describe this research here; for details, please see the papers.

The starting point for this work has been the study of infinite dimensional control canonical forms, described in paper 1. I have used canonical forms to solve an eigenvalue specification problem for certain systems with bounded control input, and in the process obtained explicit formulas for the feedback element and closed loop eigenvectors. It turns out that these formulas apply to a much more general class of distributed parameter systems in which the input element and feedback are not necessarily bounded. Since most boundary control problems have unbounded input, this is a very important class of systems. General eigenvalue specification results are obtained for these systems in paper 2.

The feedback element which solves the eigenvalue specification problem is given by an infinite series, so cannot in general be computed. It does however, lead to two finite dimensional methods - the series can be truncated to get a computable feedback element; or the resulting series for u(t) can be truncated to get a computable control function. A question arises about the control spillover properties of these schemes. We show that in both of these control schemes the closed loop performance in the higher modes is "no worse" than the open loop performance. The spillover analysis for the first method in done in paper 3, and in the second method the canonical form is used in a very natural way to prove the spillover result.

We have applied these spectral determination results to several equations modeling the vibration of elastic beams with various boundary conditions and various kinds of controls. In paper 1 we describe a class of structurally damped beams with distributed control. In this case the associated control input is bounded. In paper 2 we consider two types of boundary control for a beam: when the control is a lateral force applied at one end, the resulting input element is "admissible", in the sense given by Ho and Russell; when the control is a moment force at the boundary, the resulting input element is not admissible. In paper 4 we show that "square root damping" in a cantilever beam models structural damping, and we consider a boundary moment control. In all of these cases, we obtain sufficient conditions that a set of numbers be the closed loop eigenvalues. We do this in the case where the allowable feedback is bounded, and also in the case where we consider a larger class of "admissible" feedback elements. We compute a numerical approximation to the feedback element and the feedback control in these examples.

It should be noted that these techniques also give a new method to solve eigenvalue specification problems of finite dimensional systems. Preliminary tests indicate that this new method requires much less computer time than the standard methods.

These spectral determination results give sufficient conditions for stabilizability of a large class of systems. For example, if the control input is a moment force at the boundary, then we can find a bounded feedback control which exponentially stabilizes the system. We are unable to use our methods to do this if the control input is a lateral force at the boundary (although we can stabilize the system with an unbounded feedback.) In fact, in paper 5, Gareth Knowles and I have given necessary and sufficient conditions for a class of systems with unbounded inputs to be exponentially stabilizable using a bounded feedback. For the beam with a lateral boundary control force it is not possible to exponentially stabilize the system with a bounded feedback. Some of these results turned out to have been proved previously (with somewhat different proofs) by Ruth Curtain in a technical report.

The grant has contributed to this work in the following ways: I was able to fund visits by Professors David Russell and Gareth Knowles, and partially fund a visit by Professor Goong Chen; I have been able to purchase software to aid in my numerical work; I have been able to attend four conferences; and I have been able to devote two entire summers to research.

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